POSITIONING CONTROL OF BALL SCREW SYSTEM DRIVEN BY DC MOTOR

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by

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2014

"I hereby declare that I have read through "*Positioning Control of Ball Screw System Driven by DC Motor*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Signature : ……………………………….

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I declare that this report entitle "*Positioning Control of Ball Screw System Driven by DC Motor*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	Ting Tze Ter
Date	:	....

To my beloved father and mother.

ABSTRACT

Ball screw driven by DC motor system is an electromechanical linear actuator that translates the rotational motion into a linear motion. There many application of ball screw system in industry especially the application of Computer Numerical Control (CNC) machine. The ball screw mechanism in this project is driven by DC motor. The DC motor is use because it is easy to setup and control, has precise rotation and most importantly is low cost. As for ball screw mechanism itself, has smooth motion, not easy to wear out and high mechanical efficiency. The problem is arise when the used of conventional PID controller in the ball screw system driven by DC motor shows less adaptability to the changes of system parameter. Therefore, the objective of this project is to design an adaptive fuzzy PID controller to overcome the limitation of conventional PID controller. The performances between the conventional PID controller and fuzzy PID controller will be compared in order to validate the robustness of the fuzzy PID controller. So this project is to compare the robustness of two proposed controllers by compare the results of ball screw table position when the parameter mass of load is set to vary. The experiment is start with designing the algorithms of fuzzy PID control and conventional PID controller, then the designed algorithm is apply onto the experimental that has been setup. The performances especially the transient response and steady state error between the controllers will be collect and compare. In the end of this project the results of system performance obtained after applying with fuzzy PID controller have lower positioning error and better performances of transient responses compared to conventional PID controller.

ABSTRAK

Mekanisma skru bola yang didorong oleh DC motor adalah merupakan sistem penggerak linear elektromekanik yang menterjemahkan gerakan putaran ke gerakan linear. Terdapat banyak aplikasi sistem skru bola dalam industry terutama penggunaan Kawalan Berangka Komputer (CNC). Mekanisme skru bola dalam projek ini adalah didorong oleh DC motor. DC motor digunakan kerana ia adalah mudah untuk setup dan kawalan, mempunyai putaran yang tepat dan yang paling penting adalah kos yang rendah. Sebagai mekanisme skru bola sendiri, mempunyai gerakan yang lancar, tidak mudah haus dan kecekapan mekanikal yang tinggi. Masalah timbul apabila pengawal PID konvensional digunakan dalam sistem skru bola didoro didorong oleh motor menunjukkan kurang keupayaan menyesuaikan diri dengan perubahan parameter sistem. Oleh itu, objektif projek ini adalah untuk mereka bentuk sebuah kabur pengawal PID kabur penyesuaian untuk mengatasi had pengawal PID konvensional. Persembahan antara pengawal PID kabur akan dibandingkan bagi mengesahkan keteguhan pengawal PID kabur. Jadi projek ini adalah untuk membandingkan keputusan bola skru kedudukan meja apabila jisim parameter beban ditetapkan berubah. Eksperimen adalah bermula dengan mereka bentuk algoritma kawalan PID kabur dan pengawalan PID konvensional, maka algoritma yang direka diaplikasikan ke eksperimen yang telah siap dipasang. Persembahan terutamanya sambutan fana dan ralat antara pengawal akan ambil dan dibuat perbezaan. Di akhir projek ini hasil prestasi yang diperoleh selepas menggunakan dengan pengawal PID kabur mempunyai ralat kedudukan yang lebih rendah dan prestasi yang lebih baik daripada jawapan sementara berbanding dengan pengawal PID konvensional.

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M	-	Mass of table
J	-	Inertial of the motor
D	-	Viscous damping coefficient of the supporting bearing
La	-	Armature inductance
Ra	-	Armature resistance
Rc	-	Ball screw pitch
θ(s)	-	Angular displacement
X(s)	-	Displacement of the table
T(s)	-	Torque of ball screw
F(s)	-	Force exert on the table
Ea(s)	-	Armature voltage
Ia(s)	-	Armature current
Kb	-	Back EMF constant
Kt	-	Motor torque constant

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Positioning control is the process of controlling the mechanism position in term of linear displacement and angular displacement. The position control can be done by adding the controller inside the mechanism to achieve high performance in the form of precision or accuracy of output position. The position control done by human power nowadays is rare and hard to achieve the good performance of positioning. Due to the human limitation in error of measuring and time consuming, the various technology have been introduced to overcome these problems. One of the positioning systems is ball screw driven by motor. Therefore, positioning control system in the modern decade is highly demand by industries such as automobile industry, fabrication and metalworking industry, oil and gas industry and process and manufacturing industry. Due to high demand of positioning control from various industries, more and more of the advanced positioning controller has been introduced to overcome the limitation of the positioning system. This is because some of industries need to achieve very high precision, high speed, low error, stability and very high robustness in various conditions of environment to get better quality of positioning output response.

There are many designs of actuator mechanisms that are purposely designed to obtain different kind of specification which is need by manufacturers especially the cost, the working range, degree of freedom and performance of the system in order to reduce the financial resources burden. One of the design actuator is ball screw feed drive mechanism which convert the rotational motion into linear motion. The ball screw system is usually driven by DC motor, servo motor and stepper motor.

Before the ball screw mechanism was introduced, the used of traditional screw (ACME) was very poor in positioning and was quite easy to be damaged. Until in 1898 that there are people try to put the steel ball between the nut and the screw shaft to replace the sliding friction with rotational friction so as to improve the bad positioning. In 1949, a ball screw device was placed in the car and it became a great revolution in the application of the ball screw. Therefore, the sliding friction of traditional screw (ACME) was replaced. And in recent years, the ball screw mechanism becomes one of the components that are widely used in the industries.

The ball screw mechanism in this decade has been widely used in the machinery such as precision machine tools, industrial machinery, electronic machinery and transport machinery. For example, the commercial aircrafts use ball screw in mechanisms such as engine thrust reversers and propeller pitch controls. Furthermore, it also can be applied in the drive of the computer disk drive starter, the adjustment of the aircraft wings, and medical x-ray examination. All of these applications need the very high precision of the drive system such as DC motor, servo motor and stepper motor to drive the ball screw mechanism. But due to some drawback of DC motor, servo motor and stepper motor itself, the positioning controllers are apply into the ball screw system driven by motor to overcome the limitation and at the same time increase the performances of the system.

This project will compare the fuzzy PID controller with the conventional PID controller to obtain high adaptability and better performance of ball screw system driven by DC motor. The term of adaptability is referring to the system that can maintain the same performances in various condition of environment no matter the performance is in good or bad. The performance of the ball screw system will include the transient response, stability and steady state. The transient response have several criteria need to consider such as rise time, settling time and percentage of overshoot in order to compare the propose controller with conventional controller. Besides that, the steady state also needs to consider in comparing between the controllers by measure error between steady state value of reference input and steady state value of output signal. Therefore, the rise time will consider as the speed of the load of ball screw system to reach the destination and the steady state error will consider as the error of position between references input position with output position.

A fuzzy logic controller is proposing to improve the conventional PID controller by improving the adaption of the PID controller to the changes of system parameter. There are many type of fuzzy PID controller that proposes by many researchers. Especially the Fuzzy P controller, Fuzzy PI+PD controller, Fuzzy PI controller, Fuzzy PD controller and Fuzzy Gain Scheduling (FGS) PID controller. The performances of each fuzzy PID controller in previous research are depending on the suitability of controller to the system model itself. Another controller that proposes beside the PID controller is fuzzy PID controller. By applying the fuzzy PID controller, it is expected that the under variation of load mass, the good performance of the system will be maintain unlike the conventional PID controller.

1.2 Project Motivation

In this project, the positioning controllers were proposed and compared by using the ball screw system driven by DC motor as a medium of experiment. The positioning controllers that proposed in this project are fuzzy PID controller and conventional PID controller. Fuzzy PID controller is used to compare with conventional PID controller due to simplicity, easy to is use and it’s have high adaptability by adding the fuzzy logic controller into the conventional PID controller. The conventional PID controller is use because of its simplicity and more familiar use in many industries.

1.3 Problem Statement

In order to control the position of the ball screw system driven by DC motor, many different controllers approach has been introduce into the ball screw system driven by DC motor to achieve a better transient performance, low steady state error and low overshoot condition. The problem arise when certain parameter of ball screw system was changed when motor load inertia is changing due to high non-linear characteristic of the ball screw system, the conventional PID controller cannot adapt to the changes of system parameter that occur on the ball screw system. Therefore, the output signal performances obtained become vary according to the change of system parameter. To improve the system using the conventional PID controller, the manufacturer or the operator has to manually change the PID gain according to the change of parameter of ball screw system. As a result, the process manually changing the PID gains would consume a lot of time when the manufacturing process is still under operation.

1.4 Objectives

The objectives of this project are:

i. To design a fuzzy PID controller for the ball screw system driven by DC motor.
ii. To examine the effectiveness of the proposed controller in PTP (point to point) positioning performance.
iii. To validate the robustness of the fuzzy PID controller under variation of load mass in the comparison to the conventional PID controller.

1.5 Scopes

The scopes of this project are:

1.5.1 DC motor

a) Maximum supply voltage is 40 Vdc .
b) Reversible direction of rotation.
c) Rated speed is 1600 rpm.
d) Rated torque is 12 Ncm.
e) Terminal resistance is 7.8 ohms.
f) Rotor inductance 5 mH.

1.5.2 Ball screw mechanism

a) Ball screw lead is 8 mm (distance travel per revolution).
b) Screw shaft diameter is 8 mm.
c) Working range of the table load along the screw shaft is 282 mm.

1.5.3 Microbox

a) Input power range is 9 V to 36 V and minimum 50 W.
b) CPU is Celeron® M 1GHz, with 256MB DDR DRAM.
c) Flash memory is 64 MB Compact Flash Card (expandable to 1 GB).
d) 8 channels Single Ended 16 bits of ADC and 4 channels 16 bits of DAC of built- in I/O with ±10 V.
e) 4 channels with 24 bit incremental encoder built-in I/O (1x, 2x or 4x).
f) 8 bits from parallel port of digital built-in I/O
g) Speed up to 1 Mbps.

1.5.4 Linear encoder

a) Working range is 300 mm.
b) Resolution is 5 um/pulse.
c) Voltage rating is 5 V.
d) Contactless.
e) Read forward and reverse direction.

1.5.5 Specification and target

a) The position control is set from point to point are 10 mm, 25 mm and 50 mm along the screw shaft.
b) The mass for the load to test the real time system are 1000g, 2000g and 3000g.
c) Design a positioning conventional PID controller using root locus, frequency response and hand tuning methods.
d) The input signals for the experiment are pulse, sine wave and step.
e) The distance range use to run the experiment is up to 174 mm.
f) The requirement for position error of the system with proposed controller that expect to maintain the maximum error up to 5um under variation of load mass.

CHAPTER 2

BACKGROUND OF STUDY

2.1 Principle of ball screw system driven by DC motor

The Figure 2.1 shows the ball screw system driven by DC motor convert the electrical voltage to mechanical torque by transfers the rotational motion in the form of angular motion from DC motor to ball screw mechanism. The conversion of angular motion from stepper motor is change into linear motion through using helical raceway of screw shaft. The amplitude of voltage that apply onto the DC motor is represent as the magnitude of angular displacement the DC motor will rotate. Therefore, the greater the amplitude of the voltage applies to the DC motor the longer the angular displacement will be rotate. Then the angular displacement will be converting into linear displacement using ball screw shaft where it has helical raceway. There are consisting of two types of helical raceway in the ball screw systems which are high helix lead and fine pitch lead. In this project the fine pitch lead is used due to high resolution since one revolution is translate to short distance of linear displacement compared to high helix lead. For example, when the motor is rotate at 90 degree, the linear motion converted by screw shaft is just move in 2 mm. Therefore, the bracket of the ball screw system can move in high precision without help from the motor with higher resolution.